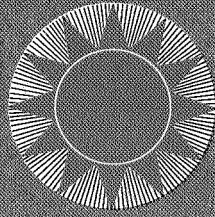


HELIOTEK

A Division of **Textron** Inc.

12500 GLADSTONE AVE., SYLMAR, CALIFORNIA 91342 • TWX 910-496-1488 • Area Code 213/365-6301



Development of Lithium Diffused
Radiation Resistant Solar Cells

Report No. 9

Third Quarterly Report

By: P. Payne

15 January 1969

JPL Contract No. JPL 952247

This work was performed for the Jet Propulsion Laboratory,
California Institute of Technology, as sponsored by the
National Aeronautics and Space Administration under Contract
NAS7-100.

**CASE FILE
COPY**

Heliotek, a Textron Company
12500 Gladstone Avenue
Sylmar, California

Development of Lithium Diffused
Radiation Resistant Solar Cells

Report No. 9

Third Quarterly Report

By: P. Payne

15 January 1969

JPL Contract No. JPL 952247

This work was performed for the Jet Propulsion Laboratory,
California Institute of Technology, as sponsored by the
National Aeronautics and Space Administration under Contract
NAS7-100.

Heliotek, a Textron Company
12500 Gladstone Avenue
Sylmar, California

This report contains information prepared by Heliotek, a Textron Company, under JPL subcontract. Its content is not necessarily endorsed by the Jet Propulsion Laboratory, California Institute of Technology, or the National Aeronautics and Space Administration.

ABSTRACT

During this quarter work on evaporated lithium as a diffusion source continued. Sintering of P/N cells with and without lithium was also studied. Particular emphasis was placed on those cells without lithium in order to isolate the effect of sintering a TiAg contact on a P/N cell from the effect of heat treatment on lithium diffused cells.

The fifth and sixth lots of lithium cells were fabricated and delivered to JPL. Yield analyses of these cells were made.

TABLE OF CONTENTS

| <u>Section</u> | <u>Description</u> | <u>Page</u> |
|----------------|----------------------|-------------|
| 1.0 | Introduction | 1 |
| 2.0 | Technical Discussion | 2 |
| 2.1 | Process Studies | 2 |
| 2.2 | Cells for Shipment | 7 |
| 3.0 | Conclusions | 13 |
| 4.0 | Recommendations | 13 |
| 5.0 | New Technology | 14 |

List of Illustrations

| <u>Figure</u> | <u>Description</u> | <u>Page</u> |
|---------------|---|-------------|
| 1. | I-V Curves of an Unsintered Lot of Lithium Diffused P/N Cells. | 4 |
| 2. | I-V Curves After Sintering of the Lot of Lithium Diffused P/N Cells Shown in Figure 1 | 5 |
| 3. | Maximum Power Distribution of Lithium Cells Fabricated for Lot 5 | 9 |
| 4. | Short Circuit Current Distribution of Lithium Cells Fabricated for Lot 5 | 10 |
| 5. | Maximum Power Distribution of Lithium Cells Fabricated for the Sixth Lot | 11 |
| 6. | Short Circuit Current Distribution of Lithium Cells Fabricated for the Sixth Lot | 12 |

List of Tables

| | | |
|----|--|---|
| 1. | Average Changes in Electrical Characteristics of P/N Cells vs Sintering Time | 6 |
|----|--|---|

INTRODUCTION

The goal of this contract is to investigate process parameters which may influence lithium solar cell performance. This includes such areas of study as the starting material, the lithium and boron diffusions, and any other processes which are included or might be added to the lithium cell fabrication process.

With respect to starting material, the type of crystal is of particular interest. The room temperature or low temperature recovery of lithium cells fabricated from crucible grown silicon has been a recent enough discovery that very little information has been obtained on these cells. The extremely good characteristics of these cells make them an important area for study, particularly in the early part of the contract period since their recovery after radiation is slower than the recovery of lithium cells fabricated from float zone silicon.

In general, lithium cells have lower efficiencies than standard 10 ohm cm N/P cells. Even so, the lithium cells compare favorably after radiation to the N/P cells. It is quite probable that if the efficiency could be increased, lithium cells would be an improvement over the N/P cell in a radiation environment. Since some high efficiency lithium cells have been obtained, the problem is one of improving uniformity and yields by improving processes and techniques. The main areas of study for improving cell efficiency will be the lithium and boron diffusions.

A major part of this program will be the fabrication of 600 experimental lithium solar cells for radiation testing and analysis by JPL. These same cells will be part of the groups of cells used for statistical analyses of the short circuit current and maximum power during the contract period.

2.0 TECHNICAL DISCUSSION

2.1 PROCESS STUDIES

Work continued during this quarter on lithium evaporations. In order to eliminate or reduce the lithium oxidation during transfer from the vacuum system to the boron diffusion furnace, various overcoating materials have been investigated. As discussed in the last quarterly report, aluminum was first investigated, but due to the enhanced oxidation which occurred when the lithium layer was covered with aluminum, aluminum was discarded as a candidate. Use of silver as a cover material was also investigated, but further work during the past quarter indicated that the lithium was alloying to the silver layer more than the silicon. Consequently the lithium was not reproducibly alloying and diffusing into the silicon. A silicon monoxide layer has also been investigated for this application. After diffusion a smooth brown layer was present which subsequently peeled off. Hot point probing and four point V/I measurements indicated that either no significant lithium diffusion occurred or some sort of insulating barrier was present. This may have been due to a chemical reaction or a deposited layer from incomplete removal of the SiO. Chemically etching of the cells in HF resulted in no change in hot point probe and V/I measurements. Measurements made after lapping approximately 0.005 inches off the lithium diffused surface, however, indicated that lithium had diffused into the cell. Use of an HF-HNO₃ acid etch also removed the barrier and made it possible to measure V/I's. These measurements revealed that a lower than normal lithium concentration had been obtained. Use of the paint-on technique for a 90 minute diffusion at 425°C typically results in a lithium concentration of $\approx 10^{17}$ atoms/cc; whereas, with the evaporation technique and the same diffusion parameters, V/I's indicate a lithium concentration of $\approx 10^{16}$ atoms/cc. Thus far, only silicon blanks have been used for investigation and the next phase will involve making

complete solar cells with this technique and analyzing the electrical characteristics. If the electrical characteristics are satisfactory, it will be necessary to do an evaluation of lithium concentrations obtained with this technique, to correlate it to the concentrations obtained with the paint-on source diffusion methods and irradiate and evaluate the recovery of the cells.

Heat treatment and sintering of P/N cells with and without lithium have indicated there is a possibility of improving cell efficiencies and uniformity with the use of the proper heat treatment. As was mentioned in the last quarterly report, sintering P/N cells with or without lithium results in an increase in short circuit current. The fact that this increase is seen in cells without lithium indicates that a gettering or annealing action unrelated to the lithium is occurring, which results in higher efficiencies. During this past quarter further investigation of heat treatments has suggested that uniformity of the electrical characteristics can also be improved. Figure 1 shows two distinct groups of I-V curves. One group has short circuits ranging from 42 to 46 mA; the other group ranges from 53 to 58 mA. The maximum power and open circuit voltages are similarly grouped. These two groups of cells were lithium diffused in the same lithium diffusion; however, they came from two different boron diffusions. The significance of this will be discussed later; the point to be made is that the difference in the I-V characteristics could not be correlated to the lithium diffusion. Sintering these cells resulted in the significant changes shown in Figure 2. As expected, the short circuit current (as well as the open circuit voltage and maximum power) of the cells increased; however, the lower output group showed increases much larger than the increases in the high output group, resulting in the total group of cells with short circuit currents ranging from 52 to 58 mA. The following are possible explanations of this situation. The stresses in the boron diffusions can vary in different diffusions. This is obvious

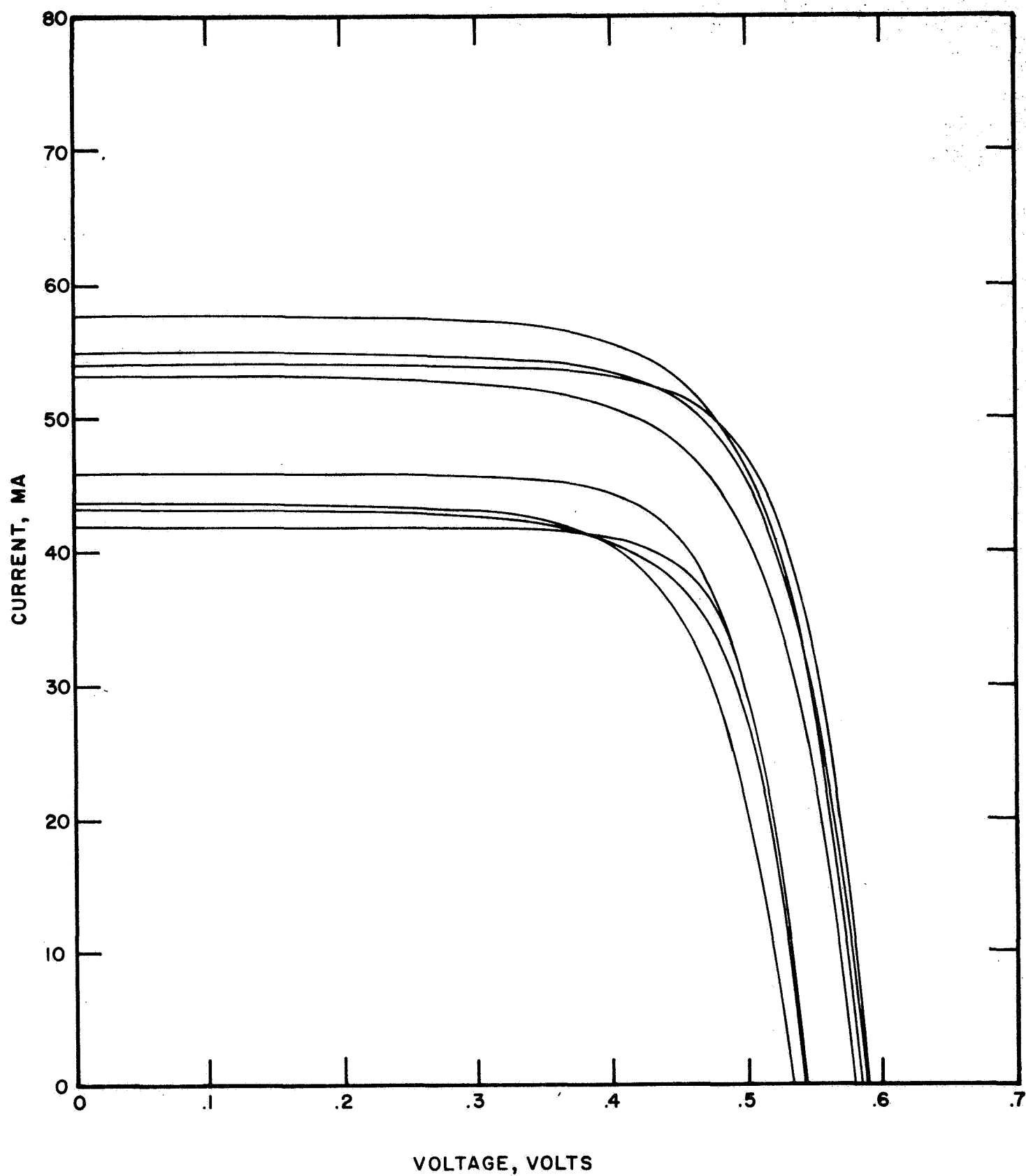


Fig. 1 I-V Curves of an Unsintered Lot of Lithium Diffused P/N Cells.

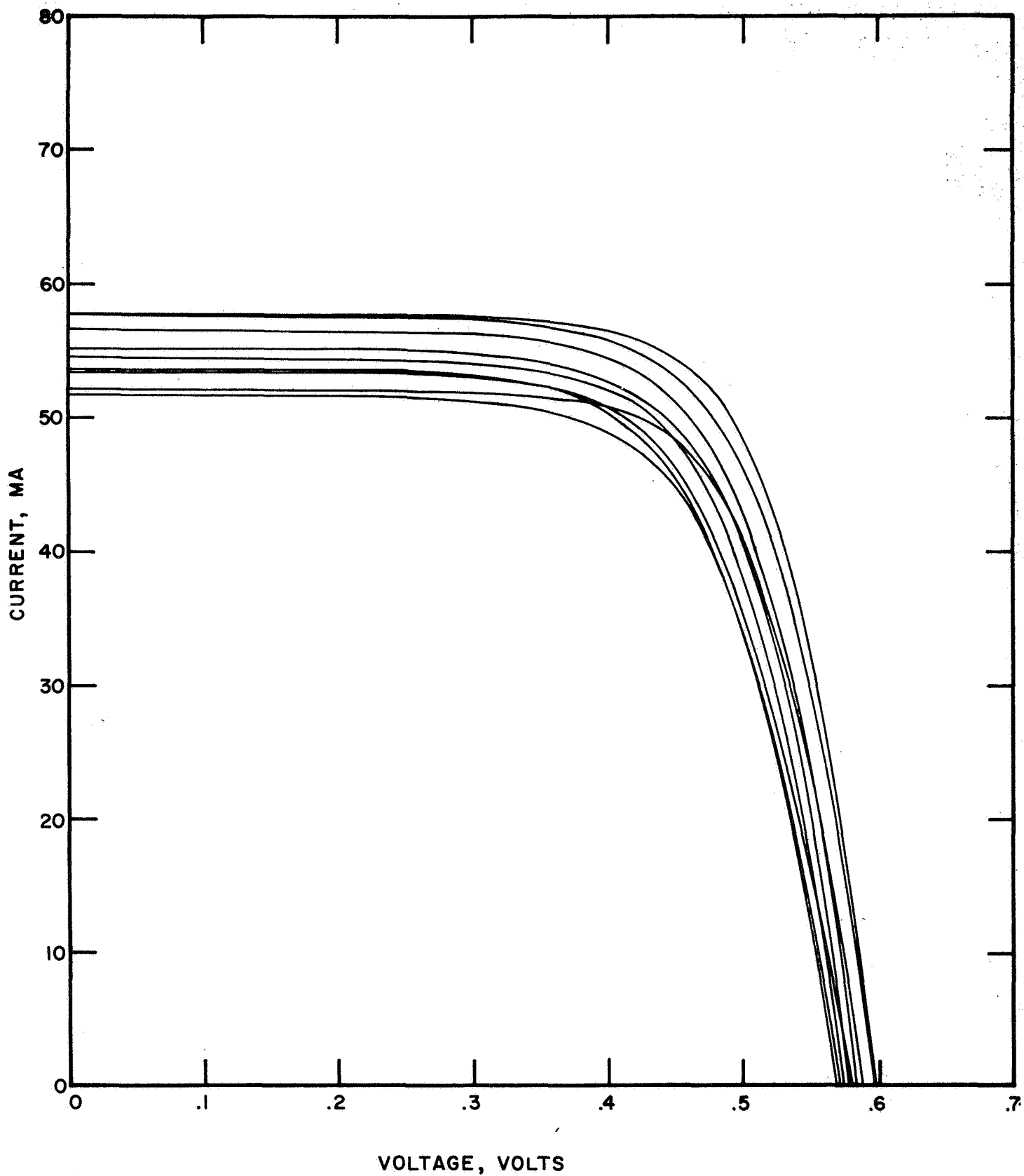


Fig. 2

I-V Curves After Sintering of the Lot of Lithium Diffused P/N Cells Shown in Fig. 1.

since some diffusion runs have bowed cells while most do not. These variations in the stresses in the cells could cause the lithium to enter the silicon lattice in a different manner, such that the electrical characteristics could be affected. The sintering then produces some type of annealing action where the stresses are relieved and/or re-arrangement of the lithium atoms occurs which causes improvement in the electrical characteristics. Or, the problem may originate in the lithium diffusion and be related to stresses that are due to particle size, amount of lithium, and/or variations in the alloying process. However, it is obvious at this point, that evaluation of the effect of sintering on lithium cells involves investigation and analyses of two aspects: the effect of sintering Ti-Ag contacts on P/N cells and the effect of high temperature heat treatment of lithium diffused cells. At this time, sintering studies are being done on P/N cells without lithium.

In a sintering experiment similar to the one above, a group of 37 20 ohm ohm cells without lithium were divided into three sub-groups: the first was sintered three minutes, the second, six minutes, and the third, twelve minutes. In each of these groups similar changes occurred; however, in most cases the degree of change varied with the sintering time. Losses occurred in maximum power, open circuit voltage, and curve factor, whereas, increases occurred in the short circuit current. The average increases and decreases in these values are shown in Table 1.

TABLE 1
Average Changes in Electrical Characteristics

| Sintering Time, min. | of P/N Cells vs Sintering Time | | | |
|-------------------------|--------------------------------|-----------------------|------------------------|---------------|
| | ΔI_{sc} mA | ΔV_{oc} mV | ΔP_{max} mW | $\Delta C.F.$ |
| 3 | +4.0 | - 23 | - .1 | - .015 |
| 6 | +3.3 | - 38 | - 2.1 | - .022 |
| 12 | +3.8 | - 44 | - 3.0 | - .042 |

The increases in the short circuit current did not seem to be highly dependent upon the sintering time. In the cases of V_{oc} , P_{max} , and C.F. the sintering time did have an effect: with increasing sintering time, greater decreases occurred. The primary cause of the decreases in P_{max} and C.F. was the significant loss in voltage in all the cells. Without the voltage loss the increase in short circuit current would have caused an increase in the maximum power, since the series resistance and curve factor were not significantly affected. The voltage loss indicates the formation of some type of barrier. In experimental work being done in another program to develop an aluminum contact on P/N lithium cells, one experiment involved subjecting P/N cells without lithium having Al grid lines and Ti-Ag back contacts to multiple sinterings in order to study the effect upon the metal contacts. These cells were sintered once with the Al grid lines only, and then two more times after application of the Ti-Ag back contacts. There were increases in maximum power, open circuit voltage, and short circuit which would indicate the two sintering processes did not adversely affect the Ti-Ag back contact even with two sintering steps. Applying this information to the current studies on cells with Ti-Ag front and back contacts would indicate that the barrier being formed is at the front contact.

2.2 CELLS FOR SHIPMENT

The fifth and sixth shipments consisted of 20 ohm cm float zone and 20 ohm cm crucible grown lithium cells, respectively. A 90 minute diffusion with 60 minutes redistribution was used for both lots; however, the float zone material was diffused at 350°C and the crucible grown silicon, at 450°C. The float zone cells were diffused at 350°C in order to evaluate the radiation recovery of cells with lower lithium concentrations and higher efficiencies. The 450°C lithium diffusion of the crucible grown silicon was done in order to investigate the effect of higher lithium concentrations on the efficiency and radiation recovery of crucible grown lithium cells. This lot of crucible grown lithium cells provides a good comparison with

Lot 2 which consisted of crucible grown lithium cells at 425°C. Figure 3 shows the maximum power distribution for 119 cells which were fabricated for Lot 5. The efficiencies on these cells were very good. Five percent of the cells had an output which was greater than 11.5 percent or 31.2 mW; 50 percent of the cells were above 28.8 mW and 95 percent were above 26.4 mW. An output of 11 percent was obtained for 24 percent of the cells and 86 percent of the cells had outputs greater than 10 percent. The average efficiency of this group of cells was 10.5 percent which was much higher than for float zone cells lithium diffused at 425°C. The short circuit distribution for these Lot 5 cells is shown in Figure 4. Five percent of the cells were 76 mA, the average was at 72 mA, and 95 percent were above 64 mA. These cells have relatively low lithium concentrations; however, they should not be eliminated for potential use in radiation environments since it has not been demonstrated that these cells will not be radiation resistant in a low level radiation environment. If this type of environment were encountered, low lithium concentration cells would have the advantage of high efficiency, as would the crucible grown lithium cells, but they would also have much faster room temperature annealing than the crucible grown lithium cells.

Figures 5 and 6 show the maximum power and short circuit current distributions for the 98 cells fabricated for Lot 6. These distribution curves are not continuous since there are two distinct distributions in the total population. The lower distributions show the characteristics of approximately the first 80 cells made. From this group of cells one can conclude that the increased lithium concentration obtained in a 450°C diffusion resulted in outputs significantly lower than those obtained in 425°C diffusions. However, toward the end of the fabrication period, additional material was needed, and some additional blanks from another silicon ingot (#2)* were used. These new blanks from ingot 2 and the last of the

*Arbitrary numbers used only for clarity.

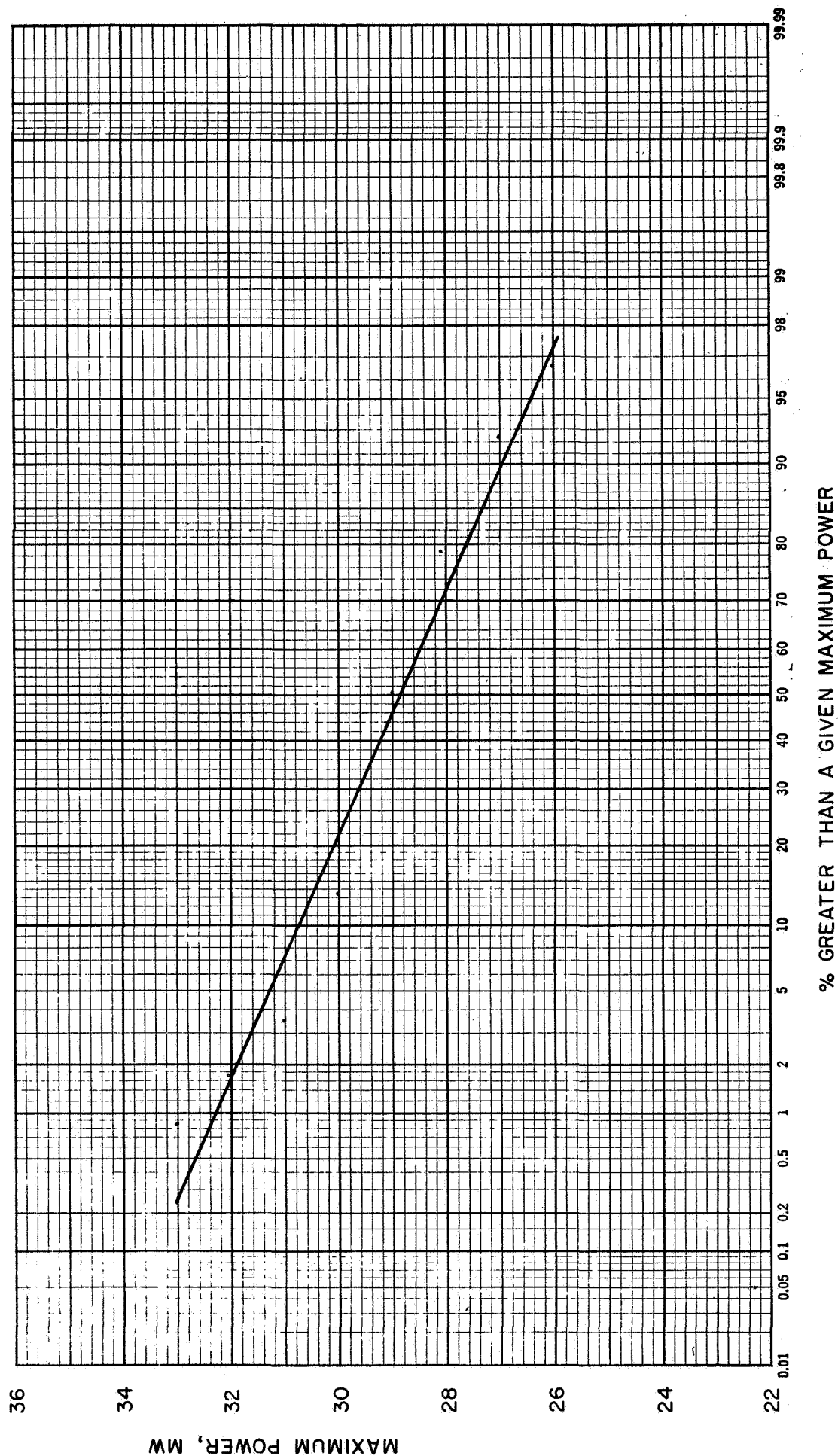


Fig. 3 Maximum Power Distribution of Lithium Cells Fabricated for the Fifth Lot (119 cells);
 20 ohm cm Float Zone Cells, Lithium Diffused 90 Minutes and Redistributed 60 Minutes
 at 350°C; measured in Solar Simulator at 140 mW/cm²

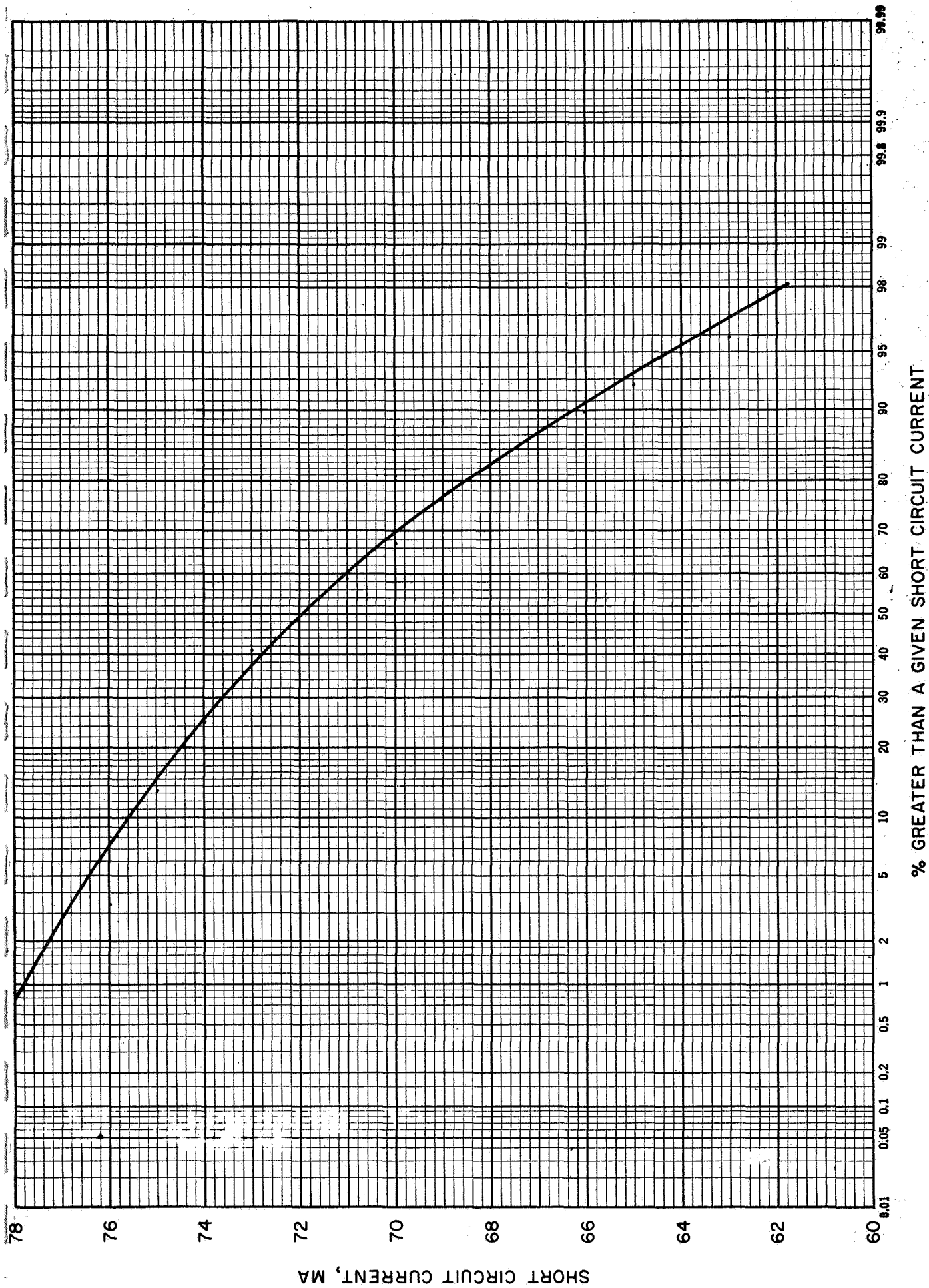


Fig. 4 Short Circuit Current Distribution of Lithium Cells Fabricated for the Fifth Lot (119 cells); 20 ohm cm Float Zone Cells, Lithium Diffused 90 Minutes and Redistributed 60 Minutes at 350 °C; measured in Solar Simulator at 140 mW/cm²

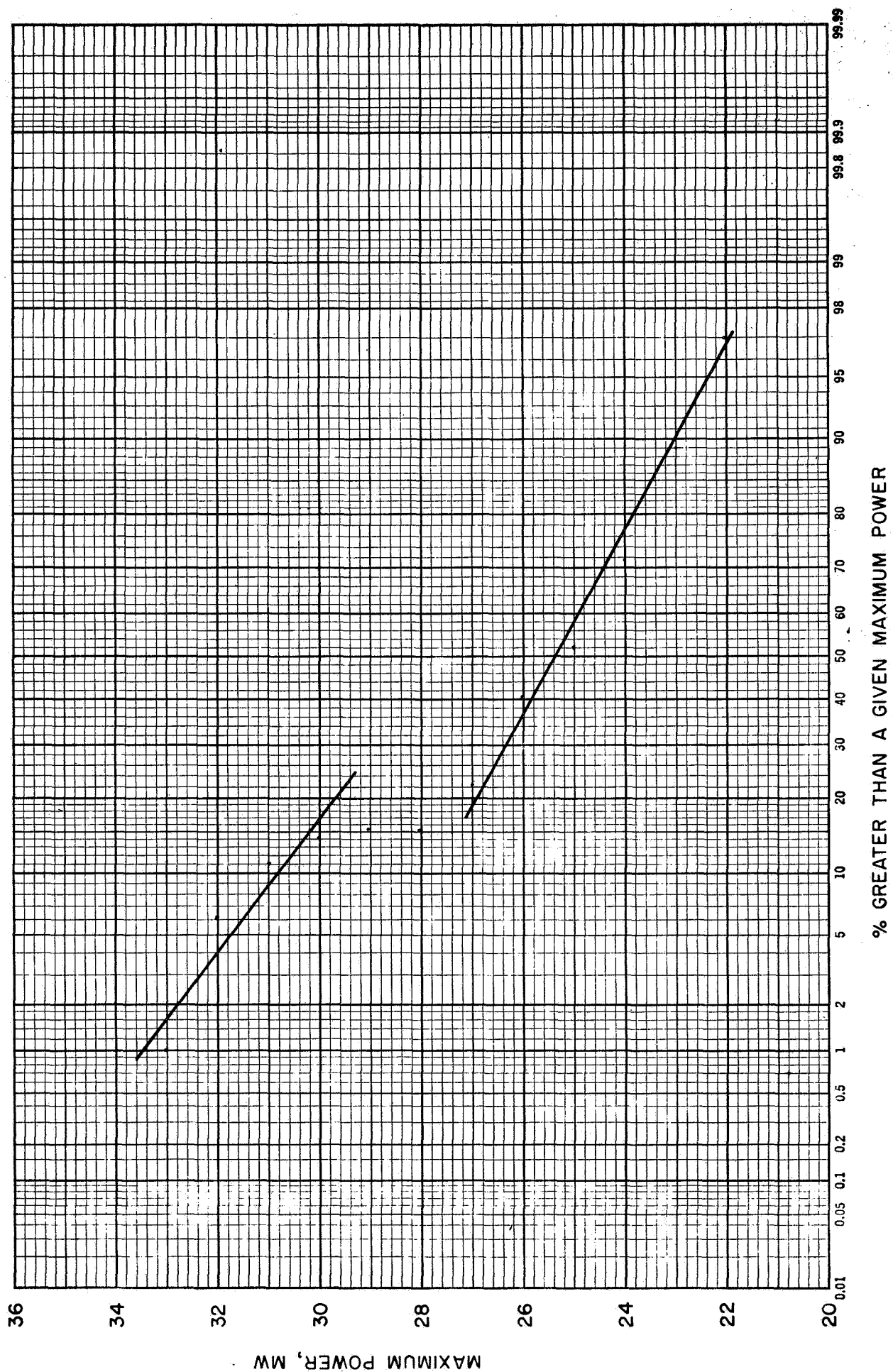


Fig. 5 Maximum Power Distribution of Lithium Cells Fabricated for the Sixth Lot (99 cells);
 20 ohm cm Crucible Grown Cells, Lithium Diffused 90 Minutes and Redistributed
 60 Minutes at 450°C; Measured in Solar Simulator at 140 mw/cm²

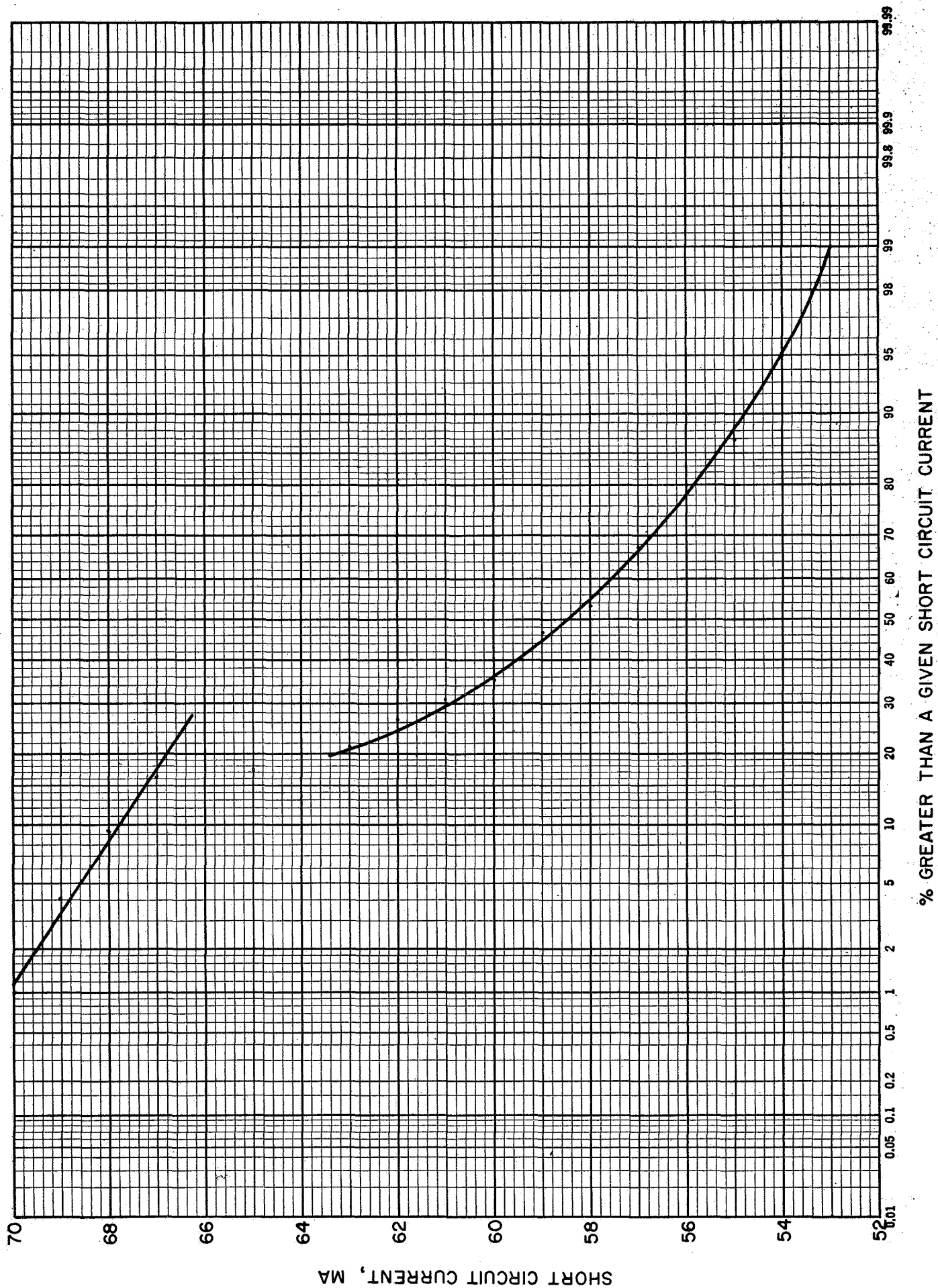


Fig. 6 . Short Circuit Current Distribution of Lithium Cells Fabricated for the Sixth Lot (99 cells); 20 ohm cm Crucible Grown Cells, Lithium Diffused 90 Minutes and

blanks left from the silicon ingot (#1)* used for the 80 cells mentioned above were diffused on the same day, although not in the same diffusion. The lithium cells fabricated from ingot #2 are those shown in the high distributions in both Figures 5 and 6. These results indicate the possibility of material variations; however, since blanks from the two different ingots were not included in the same boron diffusion, the possibility of having just extremely good boron diffusions cannot be eliminated.

3.0 CONCLUSIONS

The effect of sintering lithium cells is dependent upon both the effect of heat treating lithium diffused cells and the effect of sintering Ti-Ag contacts on P/N cells. The study of sintering P/N cells (no lithium present) with Ti-Ag contacts has indicated that some type of barrier is formed, possibly at the front contact. Preliminary investigation of sintering lithium diffused P/N cells indicated that annealing or gettering occurs which greatly increases the short circuit of the cells. Since heat treatment can improve lithium cells, while sintering Ti-Ag contacts does not seem too beneficial, it is possible that a heat treatment similar to the sintering process could be performed before application of the Ti-Ag contacts which would improve the outputs of lithium cells.

P/N float zone lithium cells can be made with efficiencies as high as 11.5 percent, if only a limited amount of lithium is needed.

High efficiencies can also be obtained with crucible grown lithium cells diffused at 450°C.

4.0 RECOMMENDATIONS

Further investigation of sintering P/N cells with Ti-Ag contacts and no lithium should be done and positive identification of the location of the barrier formation should be made. The effect of heat treatment of lithium cells should be isolated from the effect of sintering Ti-Ag contacts. Cells utilizing a lithium evaporation covered with SiO should be made and evaluated.

5.0 NEW TECHNOLOGY

None